ONE-DIMENSIONAL SIMULATION OF A 4-STROKE SI ENGINE EMPLOYING NOVEL CYLINDER HEAD CONCEPT: INTAKE AND EXHAUST FLOW INVESTIGATION

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. This project has not been accepted for any degree and is not concurrently submitted for the award of other degree.

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ABSTRACT

This project investigates the flow characteristic in novel cylinder head at various port size and runner length. Novel cylinder head engine is a design engine that operates in a 4-stroke operational cycle. This engine uses a second opposed piston in designed cylinder head that moves at half the cyclical rate of the main piston, thus giving six piston movements per cycle. Functionally, the second piston replaces the valve mechanism of a conventional engine. Intake and exhaust poppet valve is replaced with two-stroke reed valve and exhaust port similar with two-stroke engine mechanism. The flow in a pipe of an engine exhaust and/or inlet system is treated as one dimensional. This means that the pressures, temperatures and flow velocities obtained from the solution of the gas dynamic equations represent mean values over the cross-section of the pipes. 1-d simulation tool used in this investigation is GT-power. Simulation runs with limitation of port size not exceed 70% size of cylinder head and exhaust length is limit to length of the motorcycle. The parameters investigated are volumetric efficiency of engine at difference engine speed and mean pistons speed. The parameter to investigate is flow rate during motoring only. The engine speed is limited to 4000 rpm related to maximum torque of original engine. Volumetric efficiency is increase with bigger intake port and smaller exhaust port. Elongations of the exhaust pipes give an improvement potential of the engine efficiency. The optimal value to choose in the novel cylinder head from the simulation result is at intake port size of 24 mm and exhaust port 16 mm as it has the optimal efficiency. For runner length the optimal value at intake runner length 90 mm and exhaust runner length 1050 mm.

ABSTRAK

Projek ini mengkaji ciri-ciri aliran di kepala silinder baru dengan saiz pelbagai pelabuhan dan panjang paip. Novel kepala silinder enjin adalah rekaan mesin yang beroperasi dalam kitaran operasi empat lejang Mesin ini menggunakan omboh menentang kedua-dua di kepala silinder direka yang bergerak pada setengah tingkat kitaran piston utama, sehingga memberikan gerakan omboh enam pada kitaran. Fungsional, omboh kedua menggantikan mekanisme injap mesin konvensional. Intake dan exhaust injap popet diganti dengan injap buluh dua-stroke dan eksos port yang sama dengan mekanisme mesin dua-stroke. Aliran dalam paip mesin knalpot dan/atau sistem udara masuk dianggap sebagai satu dimensi. Ini bermakna bahawa tekanan, suhu dan kelajuan aliran yang diperolehi daripada penyelesaian persamaan gas dinamik merupakan nilai rata-rata di atas penampang paip. 1-d simulasi alat yang digunakan dalam penelitian ini adalah GT-power. Simulasi berjalan dengan keterbatasan saiz pelabuhan tidak melebihi 70% dari saiz kepala silinder dan knalpot panjang adalah batas untuk panjang motosikal. Parameter yang diteliti adalah kecekapan volumetrik enjin pada kelajuan perbezaan enjin dan bererti kelajuan omboh. Parameter untuk menyiasat adalah laju aliran semasa memandu saja. Kelajuan enjin terhad pada 4000 rpm yang berkaitan dengan torsi maksimum mesin asli. kecekapan volumetrik meningkat dengan port asupan yang lebih besar dan lebih kecil exhaust port.Elongations dari paip ekzos memberikan potensi peningkatan kecekapan enjin. Nilai optimum untuk memilih di kepala silinder baru dari hasil simulasi pada saiz asupan pelabuhan 24 mm dan lubang eksos 16 mm kerana memiliki kecekapan yang optimum.Untuk panjang runner nilai optimum pada panjang intake runner 90 mm dan exhaust runner panjang 1050 mm.

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LIST OF SYMBOLS

ηv	Volumetric efficiency
ρ	Density
Vd	Displacement volume
N	Engine speed
$\dot{m}a$	Mass flow rate
V_c	Clearance volume
r_c	Compression ratio
%	Percentage
Vs	Versus
C_d	Discharge coefficient
D_v	Diameter
L_v	Valve lift
A_c	Curtain area

LIST OF ABBREVIATIONS

TDC	Top Dead Center
BDC	Bottom Dead Center
ABDC	After Bottom Dead Center
ATDC	After Top Dead Center
RPM	Revolution per minute
P-V	Pressure versus volume
SI	Spark ignition

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Spark ignition (SI) engine is the most common engine that been use all over the world. In the past few years SI engine have been improved in term of efficiency and pollutant emissions. The quest for an engine which having the same or more power with higher fuel efficiency than the existing ones has started before many years. Of these the reasons developed three six stroke engines is undergoing tremendous research works. During every cycle in a typical four stroke engine, piston moves up and down twice in the chamber, resulting in four total strokes and one of which is the power stroke that provides the torque to move the vehicle. But in a six stroke engine there are six strokes and out of these there are two power strokes. The automotive industry may soon be revolutionized by a new six-stroke design which adds a second power stroke, resulting in much more efficiency with less amount of pollution. The six-stroke engine uses a second opposed piston in each cylinder that moves at half the cyclical rate of the main piston, thus giving six piston movements per cycle. Functionally, the second piston replaces the valve mechanism of a conventional engine but also increases the compression ratio. The currently notable designs in this class include two designs developed independently: the Beare Head engine, invented by Australian Malcolm Beare, and the German Charge pump, invented by Helmut KottmannGriffin six-stroke engine.

1.2 PROBLEM STATEMENT

Novel cylinder head give a positive effect on the performance. In order to improve and to get a batter other factor and parameter need to investigate. In this study it focuses in the intake and exhaust flow. The design will be using reed valve for the intake system and exhaust port for the exhaust system. The volumetric efficiency of the design is use to measure the effectiveness of the engine.

1.3 OBJECTIVE

The objective of this project is to:

i. To model the intake and exhaust ports of novel cylinder head in GT-Power
ii. To investigate the flow characteristic of various port sizes and timing in GT-Power.

1.4 SCOPES

This study is limited to the intake and exhaust of a small engine which employing novel cylinder head. The parameter to investigate is flow rate during motoring only. The engine speed is limited to 4000 rpm related to maximum torque of original engine. The various port size is varies not exceed 70% size of cylinder head.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The novel cylinder head design had shown a positive effect on the performance and also to the environment compare to the original engine. In order to get a batter performance, few other factors need to be considered. Some of the factors are optimizing intake flow, valve timing, stress analysis, fuel injection and ignition timing, heat transfer analysis, fabrication and testing. These studies focus in modeling and simulate intake and exhaust system for novel cylinder head using GT-power as 1-D simulation tool. The investigation is on the flow characteristic when using various port sizes, length and timing.

2.2 ENGINE CYCLES

Operating cycle of internal combustion engine can be divided into a sequence of separate processes which is intake, compression, expansion, and exhaust. With models for each process, a simulation of a complete engine cycle can be build which can be analyzed to provide information on engine performance.

2.2.1 Four-Stroke Operating Engine Cycle

The first person to actually build a car with this engine was German engineer Nikolaus Otto. That is why the four-stroke principle today is commonly known as the Otto cycle and four-stroke engines using spark plugs often are called Otto engines. The Otto cycle consists of adiabatic compression, heat addition at constant volume, adiabatic expansion and rejection of heat at constant volume. In the case of a four-stroke Otto cycle, there are also an isobaric compression and an isobaric expansion, usually ignored since in an idealized process those do not play any role in the heat intake or work output.

Four –stroke operating engine cycle is called an Otto Cycle. The operating cycle is approximated by the air-standard cycle as shown in Figure 2.1.

The intake stroke starts with piston at TDC and is at an inlet pressure of one atmosphere. It is a constant pressure process 1-6 Figure 2.1.

The second stroke of the cycle is compression stroke, which is an isentropic compression from BDC to TDC process 1-2 Figure 2.1. In a real engine, the beginning of the stroke is affected by the intake valve not being fully closed until slightly after BDC and at the end if compression it is affected by the firing of the spark plug before TDC. The combustion process 2-3 in Figure 2.1 is at constant-volume conditions. In the real engine, combustion stated slightly BTDC and terminated a little ATDC.

Combustion process occurred in a closed constant-volume increase pressure and temperature in cylinder. The very high pressure generates the power stroke or expansion stroke process 3-4 Figure 2.1. High pressure on the piston face forces the piston back towards BDC and produces work and power output of the engine.

Near the end of power stroke of a real engine cycle, the exhaust valve is opened and the cylinder experiences exhaust blow down process 4-5 Figure 2.1. A large amount of exhaust gas is expelled from cylinder, reducing pressure to exhaust manifold. The exhaust valve opens BBDC to allow finite time of blow down to occur. The pressure within the cylinder at the end of exhaust blow down has been reduced to about one atmosphere.

The exhaust stroke process 5-6 Figure 2.1 occurs as the piston travel from BDC to TDC. The process occurs at constant pressure due to the open exhaust valve.

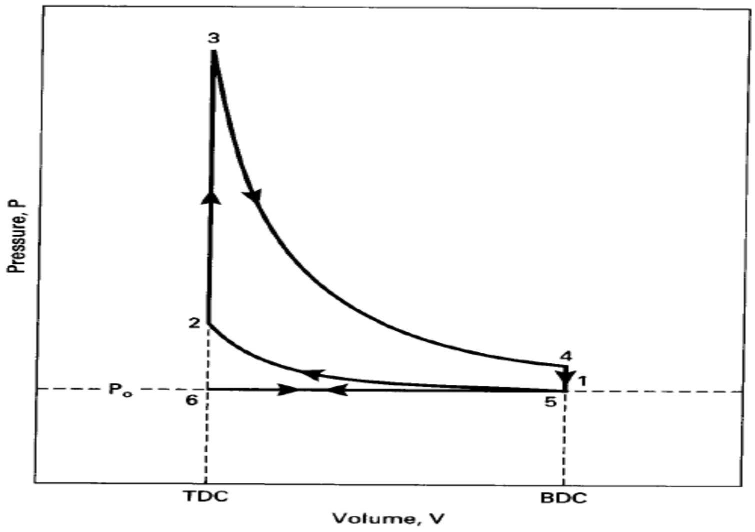

Figure 2.1: Otto cycle P-V diagram

Source: Pulkrabek,1997

2.3 INTAKE SYSTEM

The object of the intake system is to deliver the proper amount of air and fuel accurately and equally to all cylinders at the proper time in the engine cycle. Flow into an engine is pulsed as the intake valves open and close, but can generally be modeled as quasi-steady state flow. The intake system consists of an intake manifold, a throttle, intake valves, and either fuel injectors or a carburetor to add fuel. Fuel injectors can be mounted by the intake valves of each cylinder, at the inlet of the manifold, or in the cylinder head. The primary components of the automotive intake system are: intake manifold, throttle body/carburetor, and air induction components such as air cleaner and ducting.

Air cleaners filter the air before it reaches the engine. They remove abrasive particles which cause wear and damage. The filter must stop minute particles without restricting air-flow. Most air cleaners trap abrasive particles using a pleated dry paper element, but some use the dust-attracting property of oil. The air cleaner on a multi-point fuel injected engine uses a dry-type element. It is connected to the throttle body by a duct. For optimum performance, it needs to be supplied with cool, clean air.

The intake manifold carries the air of the air-fuel mixture to each cylinder. In spark-ignition engines, fuel is either mixed with the air at the entrance to the manifold, or injected close to the cylinder head.

To maintain ideal combustion conditions and reduce emissions, many air cleaners include a system to maintain air-intake temperature, regardless of outside air temperature.

2.3.1 Intake Valve

Intake valve of most internal combustion engines are poppet valves that are spring loaded closed and pushed open by the engine camshaft. Most of the valve are made form a hard alloy steel (Pulkrabek,1997).

The distance which the valve opens is called valve lift Figure 2.2. Due to the constant opening and closing of the valves, the cross sectional area through which the flow passes through changes. This area is referred to as the effective area. This area is defined as in Eq. (2.1).Where A_c is curtain area and C_d is discharge coefficient.

$$A_e = A_c\,(q)\,C_d(q) \qquad (2.1)$$

The curtain area, A_c, can be defined in several ways. A simple definition of the curtain area is given by Eq. (2.2). Where D_v is diameter of the valve and L_v is valve lift.

$$A_c = 3.14159 \times D_v\,L_v \qquad (2.2)$$

The lift and the discharge coefficient both vary with the crank angle. The discharge coefficient is determined experimentally. This coefficient accounts for the real gas flow effects.

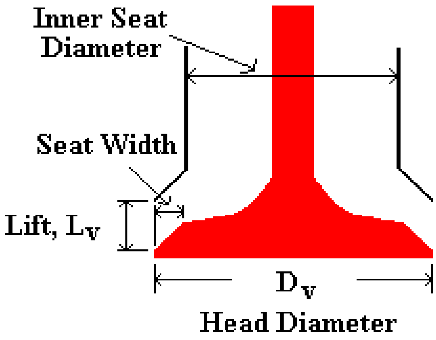

Figure 2.2: Schematic of the poppet valve

Source: Taylor

2.3.2 Disc valve

The disc valve design is emanated from East Germany in the 1950s (Blair, 1996). Most disc valve has timing characteristic and is usually fabricated from spring steel.

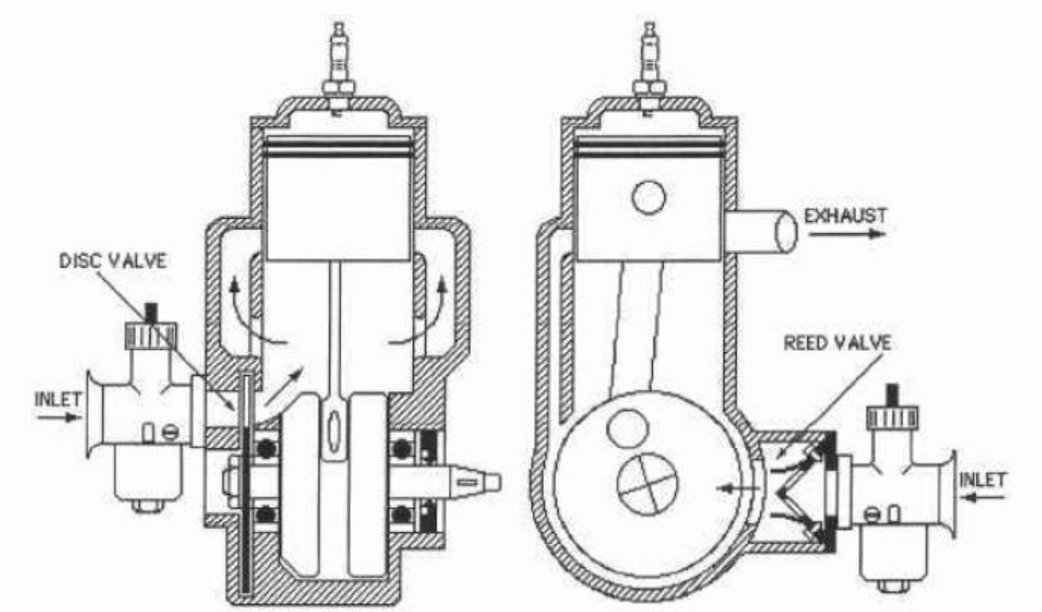

Figure 2.3: Disc valve and reed valve control of the inlet system

Source: Blair, 1996

2.3.3 Reed valve

Reed valve Figure 2.4 have and elastic reed that rest on a basic body. It controls gas transfer in the intake port. Most reed valve is design as V-block Figure 2.3 and the material used for the reed petals are either spring steel or composited material.

The reeds are self acting and open when vacuum builds in the engine crankcase so that the air or fresh mixture can enter freely. As the pressure increased in the crankcase up to pressure in the intake manifold, the reeds automatically close, thus preventing backflow of the induced charge.

Figure 2.4: Reed valve

Source: A. Angeletti

2.4 EXHAUST SYSTEM

During engine operation, each time the exhaust valve opens pulses of hot exhaust gases are forced into the exhaust manifold. These hot, rapidly expanding gases produce a lot of noise, some of it at very high frequency. The exhaust system does several jobs. It has to reduce the noise of the exhausting gases to acceptable levels. It has to discharge the gases safely, far enough away to prevent them re-entering the vehicle.

Some of these gases are highly poisonous. In an enclosed space, carbon monoxide can cause death in minutes. It is odorless and colorless, which makes it difficult to detect, and removing it is especially important. In modern vehicles, it also keeps harmful emissions to a minimum.

The exhaust system is designed to enhance engine operation. A well-designed system can improve drivability and performance. In this simplified model, burned gases exit the cylinder through the exhaust port and pass into the exhaust manifold.

The first pipe is usually called the engine pipe. It is connected to the outlet of the manifold which carries the exhaust gases to the muffler, which reduces exhaust noise. Exhaust gases are then discharged through a tail pipe, usually at the rear, or sometimes, to the side or above the vehicle.

The primary components of the automotive exhaust system are: exhaust manifold, engine pipe, catalytic converter, exhaust brackets, muffler and components such as the resonator and tail pipe. The exhaust manifold collects exhaust gases as they leave each cylinder and directs them into the exhaust system. The exhaust pipe carries the hot exhaust gases to where they can be discharged into the atmosphere.

2.5 INTAKE AND EXHAUST FLOW

The intake and exhaust system are important because these system govern the air flow into the engine cylinders. The higher the air flow, the larger the amount of fuel that can burn and greater the power produced. The importance parameters are volumetric efficiency for four-stroke engine or scavenging and trapping efficiencies for two-stroke engine.

Mass flow through the intake valve into a cylinder is shown in Figure 2.5. Reverse flow can result when valve overlap occurs near TDC. Reverse flow out of the cylinder will also occur at lower engine speeds as the intake valve is closing ABDC, as previously explained. Intake valves normally start to open somewhere between 10° and 25° BTDC and should be totally open by TDC to get maximum flow during the intake stroke. The higher the speed for which the engine is designed, the earlier in the cycle the intake valve will be opened. In most engines valve timing is set for one engine speed, with losses occurring at any lower speed or higher speed. At lower than design speed the intake valve opens too early, creating valve overlap that is larger than necessary. This problem is made worse because low engine speeds generally have low intake manifold pressures. At higher than design speeds, the intake valve opens too late and intake flow has not been fully established at TDC, with a loss in volumetric efficiency.

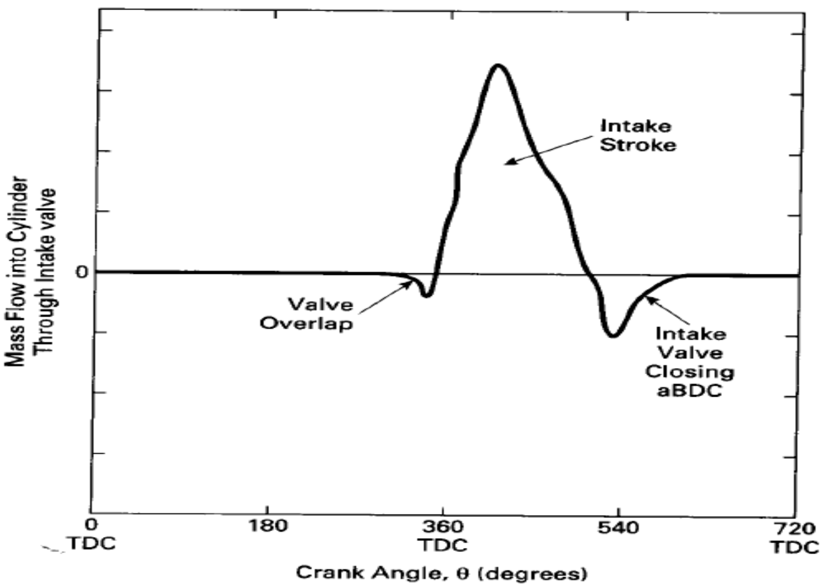

Figure 2.5: Flow of air-fuel mixture through the intake valve into engine cylinder

Source: Pulkrabek,1997

Figure 2.6 shows the flow of gases through the exhaust valve out of the cylinder. When the valve is first opened, blow down occurs with a very high flow rate due to the large pressure differential. Choked flow will occur at first, limiting the maximum flow rate. By the time the piston reaches BDC, blow down is complete, and flow out of the exhaust valve is now controlled by the piston during the exhaust stroke. The piston reaches maximum speed about halfway through the exhaust stroke, and this is reflected in the rate of exhaust flow. Towards the end of the exhaust stroke, near TDC, the intake valve opens and valve overlap is experienced. Depending on engine operating